

Detectors for proton beam-dump experiments



ATHANS HATZIKOUTELIS
INTENSITY FRONTIER WORKSHOP
IF5: NEW LIGHT, WEAKLY COUPLED
PARTICLES
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ARGONNE NATIONAL LABORATORY

Outline

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- No motivation.
- Proton beam –dump examples.
- One example of using existing detectors.
- Two designs for new detectors.

Low energy proton accelerator sources

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1 GeV Program of Project X

	Stage 1		Stage 2	
	120	60	120	60
Beam Power	984	984	980	980
Protons per second	6.2×10^{15}	6.2×10^{15}	6.2×10^{15}	6.2×10^{15}
Pulse length	CW	CW	CW	CW
Bunch spacing**	Programmable		Programmable	
Bunch length (FWHM)	.04	.04	.04	.04

SNS

**Spallation Neutrino
Source**

Proton beam energy – 1.0 → 1.4 GeV

Intensity - $9.6 \cdot 10^{15}$ protons/sec

Pulse duration - 380ns(FWHM)

Repetition rate - 60Hz

Total power – 1.0 → 3 MW

Liquid Mercury target

Medium and High Energy sources

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- FNAL BOOSTER

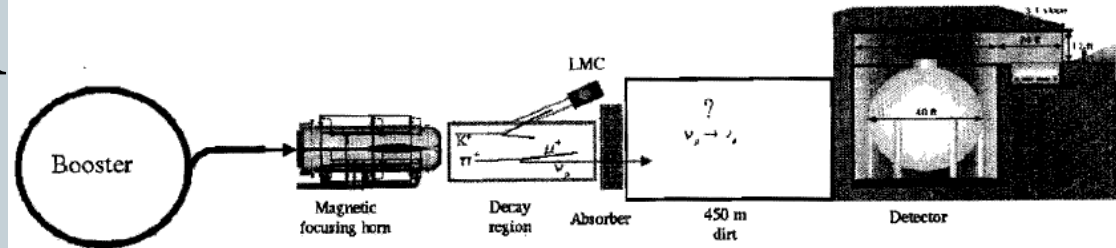
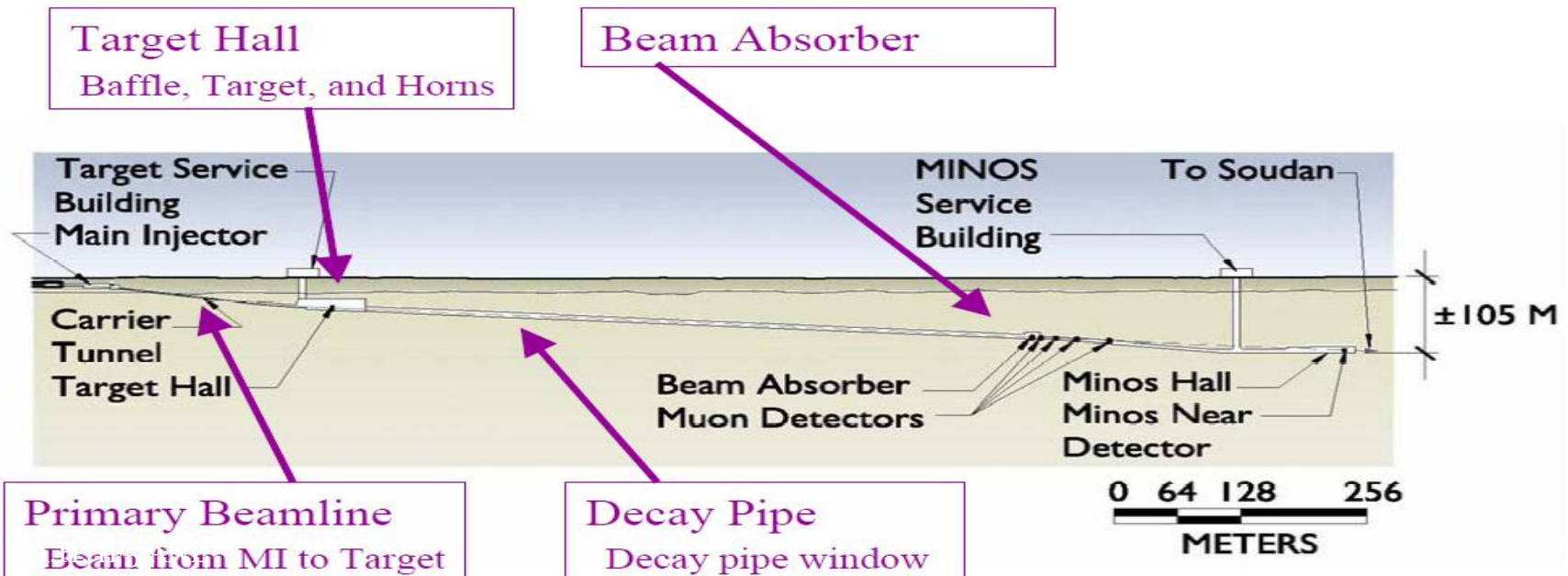


Figure 1: A schematic drawing of the MiniBooNE experiment.

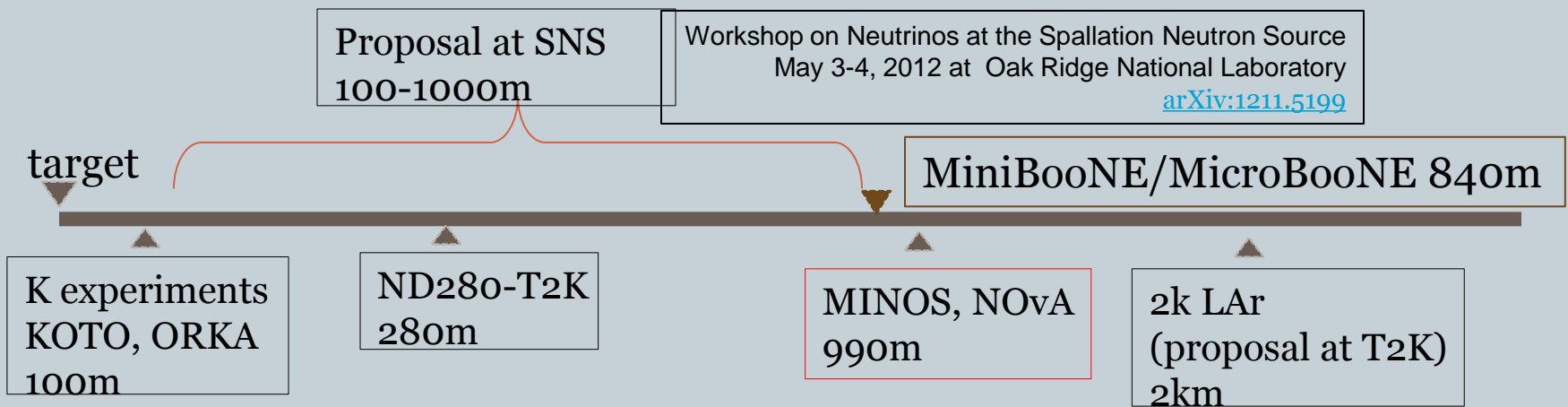
- FNAL NuMI



Example of using existing neutrino Near Detectors

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- Large number of protons on target (10^{21} POT per year).
 - Project X would provide 10x the current intensity.
- Exotic particle flux is very forward collimated and remains constant with distance from the target.
- Fair distance from the target
 - Backgrounds from neutrino interactions are low ($\sim 1/R^2$),



More on Near Detectors

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- Designs are sensitive to energy and direction reconstruction of protons, neutrons, muons, electrons, and photons that are produced by exotic particle decay/scatter.
- There have been observed significant unexplained electron/photon-like excesses in both neutrino and anti-neutrino mode.
- Good beam and event reconstruction timing (\sim nsec)
- Geometry restriction make the sensitive to heavy (subluminal) particles ($> \text{MeV}$).

Model independent measurement at NOvA ND

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$$N_{A' \rightarrow e^+ + e^-}(M_{A'}) = \int F_{lux} * \left(1 - e^{-\frac{P_{ath} * M_{A'}}{\tau_{A'} P}}\right) * \epsilon_{pair}^{eff} A_{ccept} dP_{ath} d\Omega$$

Number of pairs

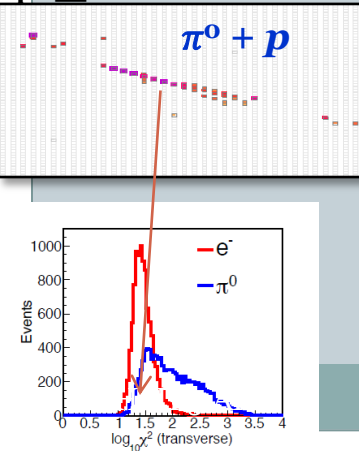
Flux of A'
from the
target

Momentum and Decay
path distributions,
from Mass, and
lifetime of an A'

Pair detection efficiency
from calibration/
reconstruction,
and detector acceptance
from dimensions and
position.

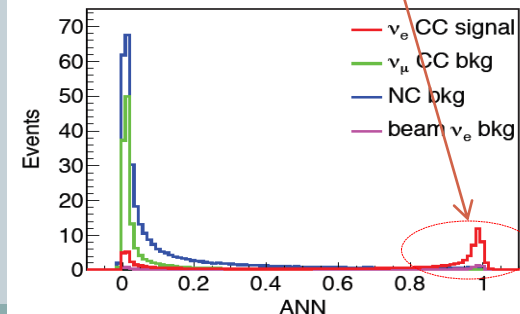
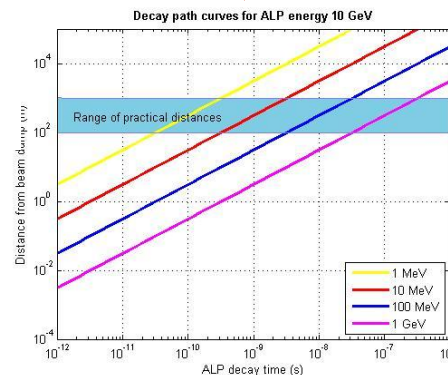
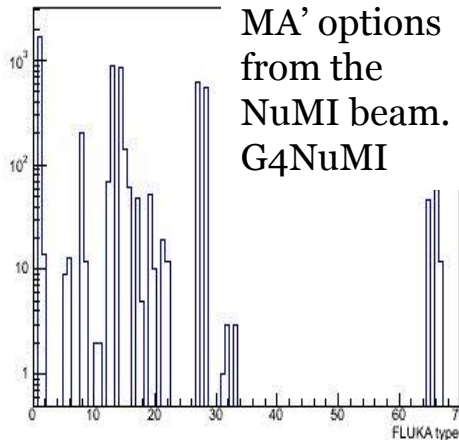
Limits from physical
choices of the
experiment

Background: pairs
from unrecognized
pi_zeros



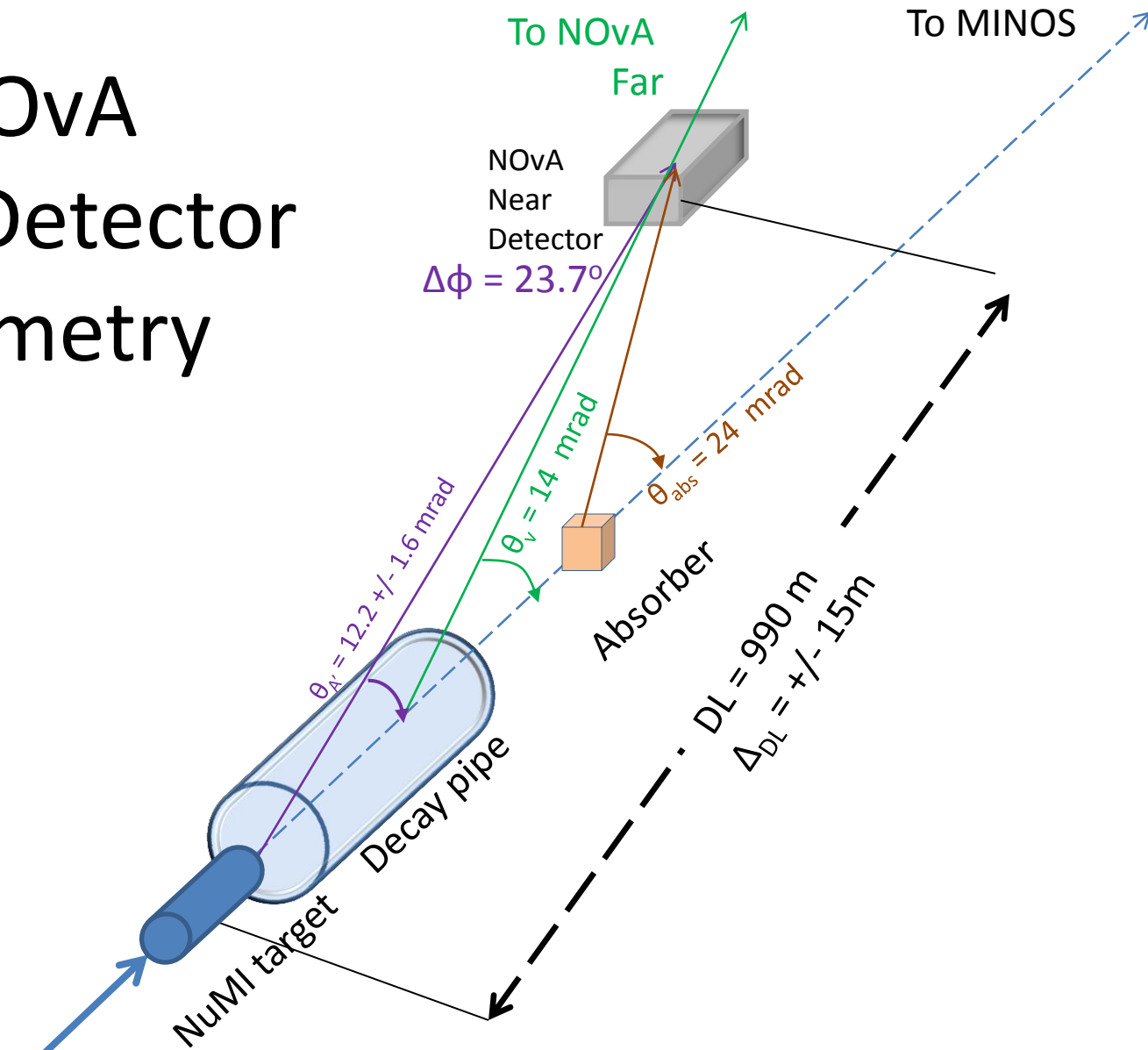
Particles in all generations

MA' options
from the
NuMI beam.
G4NuMI



NOvA Near Detector geometry

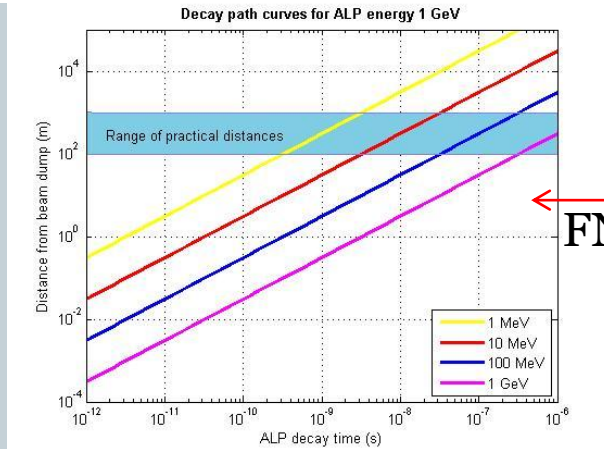
Protons
 $E_p = 120 \text{ GeV}$
 10^{15} bunch,
 2.2 sec cycle



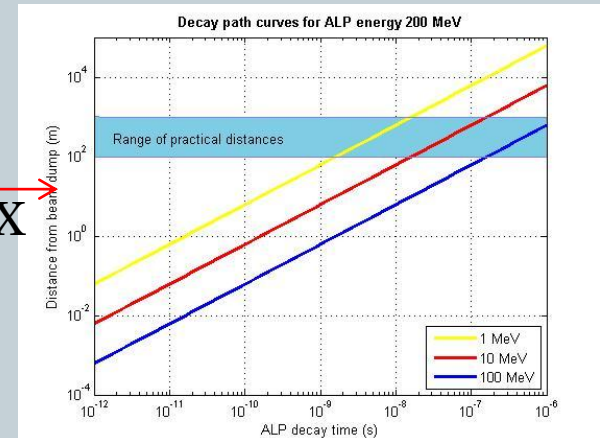
Decay Path sensitivity at different beam dumps

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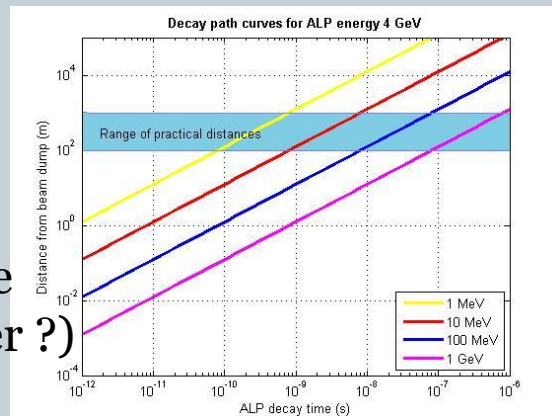
Examples at
an 1 GEV
accelerator
source



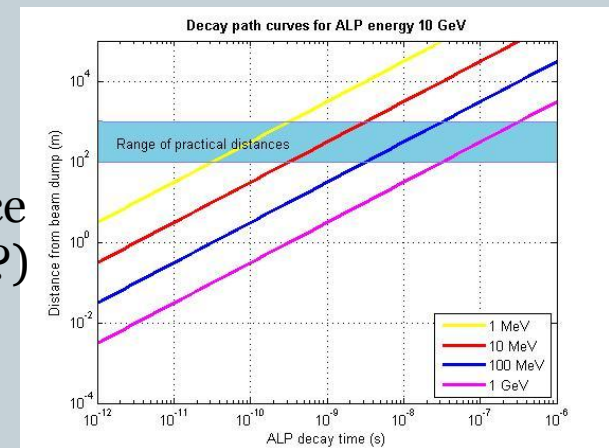
ORNL SNS
FNAL Project-X



Examples at
>4 GeV source
(FNAL Booster ?)



Examples at
>10 GeV source
(FNAL NuMI ?)



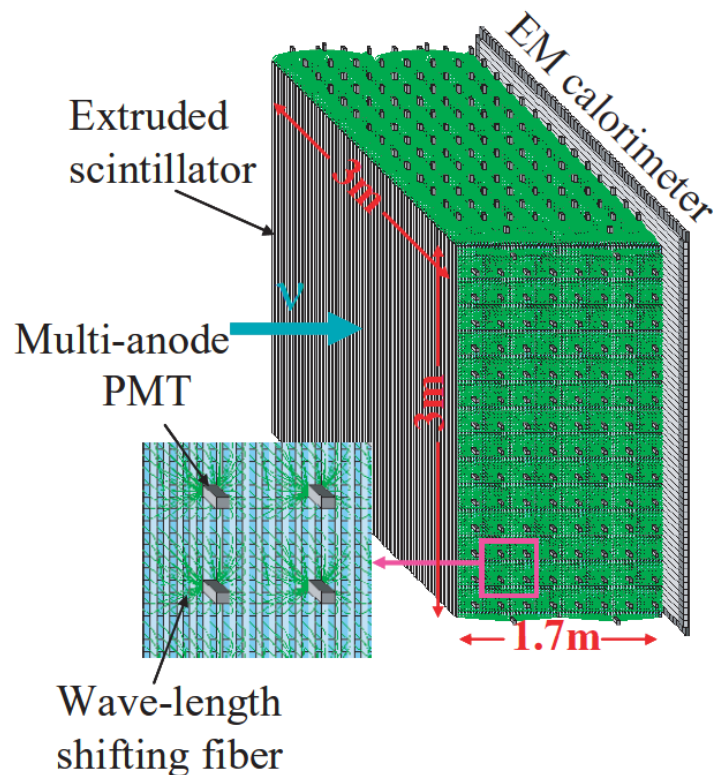
Decay path measured from the point of creation : in the target, decay pipe, final absorber, etc

Decay-path scans: Movable detectors

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- Fully active scintillator bar based.
- **Example: SciBar= 15k bars, $1 \times 2 \text{ cm}^2 \times 3 \text{ m}$, 1mm WLS fibers, 64 layers.**
- **Example of cost from SciNOvA report \$ 2M and 23 month construction.**
- For a truck-able system on the surface an extra active cosmic veto is necessary.
- Limitation in weight.
 - Can be divided to platforms
 - (1 detector +1 electronics)
- Much wider decay-path scans.
 - Covers wider ranges of the parameter phase-space.

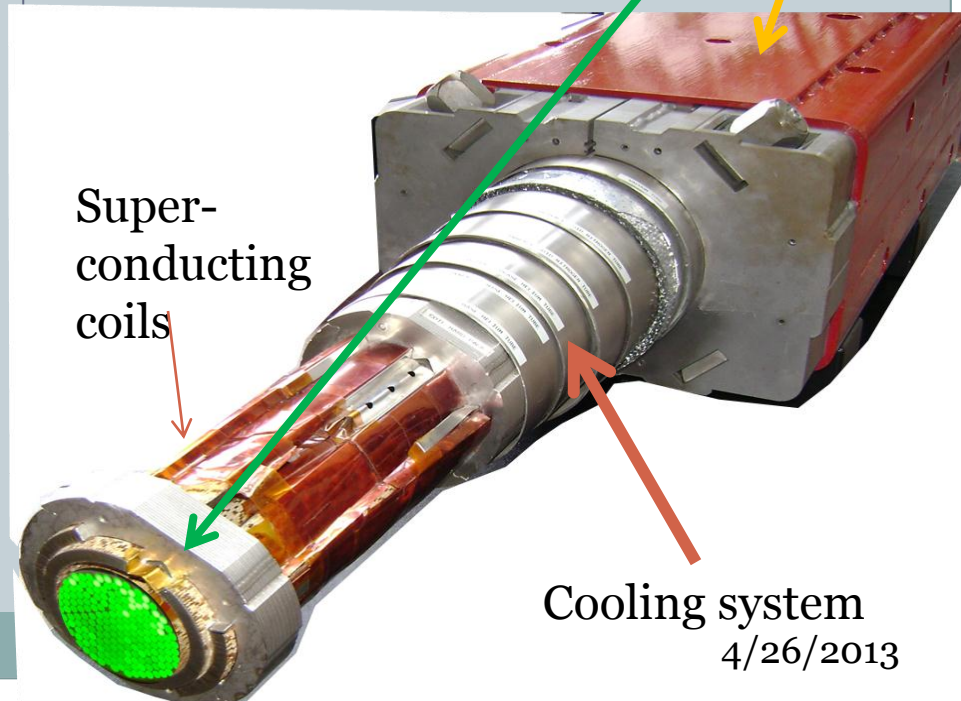
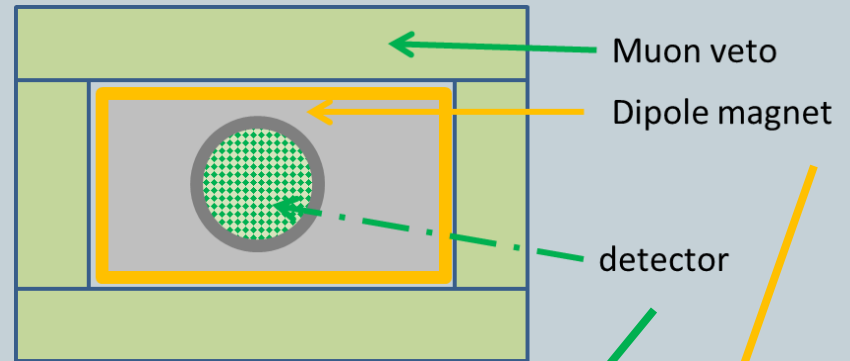
SciBar from K2K exp.



Dark Photon detector

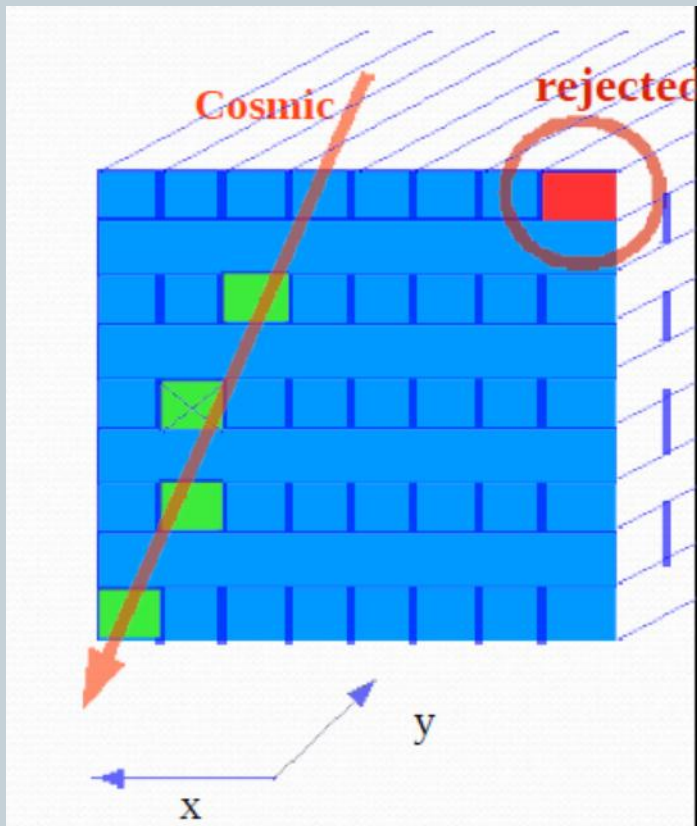
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- Take advantage of the B-L coupling of D-Photons.
- Positioned in front of the particle detector.
- Use of the FNAL new High Field dipoles.
 - $B=11.5$ T, $L=2$ m.
- Center space filled with a detection system.
 - Detector R&D required:
 - ✦ What kind of scintillator rods can operate at LHe temperatures.
 - ✦ Can a volume with liquefied gas work?
 - LXe, LAr, ... L??
 - Readout R&D
 - ✦ Can we use APD or SiPM?
 - ✦ Can we use Micromegas?



Active muon veto design.

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Scintillator based/ $2 \times 4 \text{ cm}^2$ / 6-10 layers/
X-Y orientation.

Covers large areas economically.

Top + Bottom arrays can perform muon-
tomography.

Proven technique to id cosmic tracks
within 1mm.

Readout by the same method and DAQ
system.

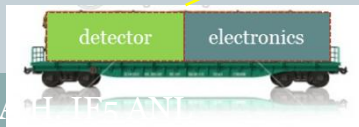
Movable detector at the ORNL SNS

proposal from 2012: [arXiv:1211.5199](https://arxiv.org/abs/1211.5199)

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Main target

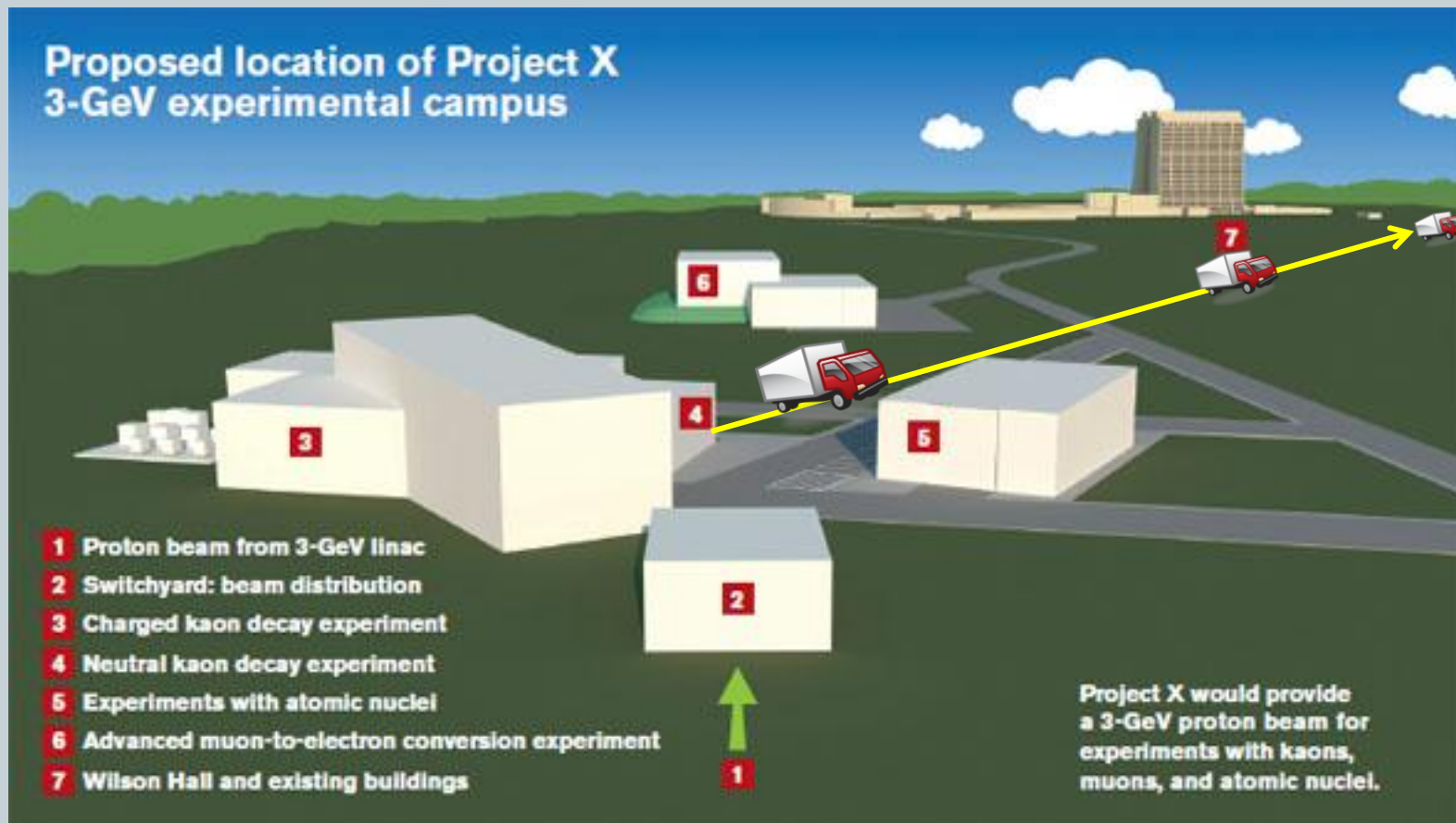


Rails can carry a detector as big as a container, larger acceptance options. Permanent arrangement may not be problem (different state, and different funding source than the FNAL)

4/26/2013

Truck-able detector at FNAL

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Positioned in a straight line with the 3GeV beam beyond the beam dump of the muon campus.

Proposed Project X Site

Proposed detectors for NLWCP at Project X campus

A truck-able detector can take advantage of the extends of the FNAL campus.

May require renting space from the county if it can be placed outside.



Discussion and outlook

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- **Experimental strategy: Economy reasoning favors multi-purpose experiments.**
 - Small : in particle physics scales (and costs).
 - Making a detector mobile can scan various ranges of mass.
 - ✦ It improves sensitivity (for each mass, scans lifetime ranges instead of a value).
 - ✦ Can be included in smaller grants, built by smaller collaborations.
 - ✦ Beam-dump: rarely prime area for experiments
 - Can share source (dump) with other experimental efforts/ideas.
- **Detector design: Tracker /calorimeter combination.**
 - Popular around neutrino experiments, proven technique.
 - Good vertex and mass reconstruction can scan decay vertices closer to the interaction point.
 - ✦ Slower /heavier particles. Increase the scanned phase space.
- **Signature: Di-particle with vertex in the beam-line.**
 - Electron, muon, or pion pairs depending on the mass.
 - Mass reconstruction provides the particle mass.
 - Signals excess gives the coupling strength to the pair.
 - ✦ Life time and mass are measured independently from each other.
 - ✦ Overall measurement is also model independent.
- **Technologies needed**
 - High magnetic fields. Will improve the sensitivity by B^2 .
 - ✦ Can be 16T/ 10T respectively with new materials.
 - ✦ Can add +1 or 2 T with cooling to 1.7 K
 - Detectors for vertex searches (pixel).
 - ✦ Fast, radiation hard.
 - Faster DAQ, High-level Triggering,

Extra slides

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Light mediators: π^0

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$$\frac{N_{signal}}{N_{bkgd}} = N_{\pi^0} * \underbrace{BR(\pi^0 \rightarrow \gamma A') * BR(A' \rightarrow e^+ + e^-)}_{\text{This is what it is estimated from the measurement}} * \underbrace{\epsilon_{pair} * A_{ccept}}_{\text{Detector properties}}$$

From beam simulations

- SINDRUM: $M_{A'} = 25\text{-}120\text{MeV}$, $BR \sim 10^{-6}$
- WASA: $M_{A'} = 30\text{-}90\text{ MeV}$, $BR \sim 10^{-6}$
- NOMAD : $(M_{A'}, P_{A'}) = (<95\text{MeV}, 4\text{GeV}) \rightarrow BR \sim 10^{-15}$

HS, DM particle Detector design

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- High granularity fully active

- Examples:

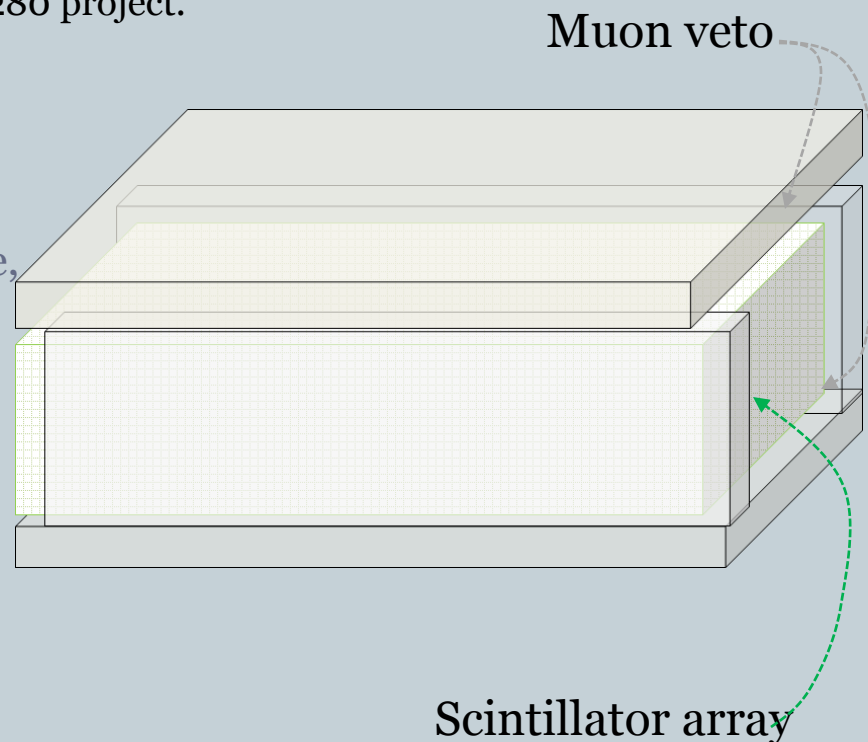
- ✦ SciBar from K2K/ PioDet or FDG from T2K ND280 project.

- Redesign parameters:

- 1x2 cm x 2m bars
 - Double the depth to 120 layers.
 - Added active veto for operation on the surface,
 - ✦ covering all 6 sides.

- Upgrade from the proposals:

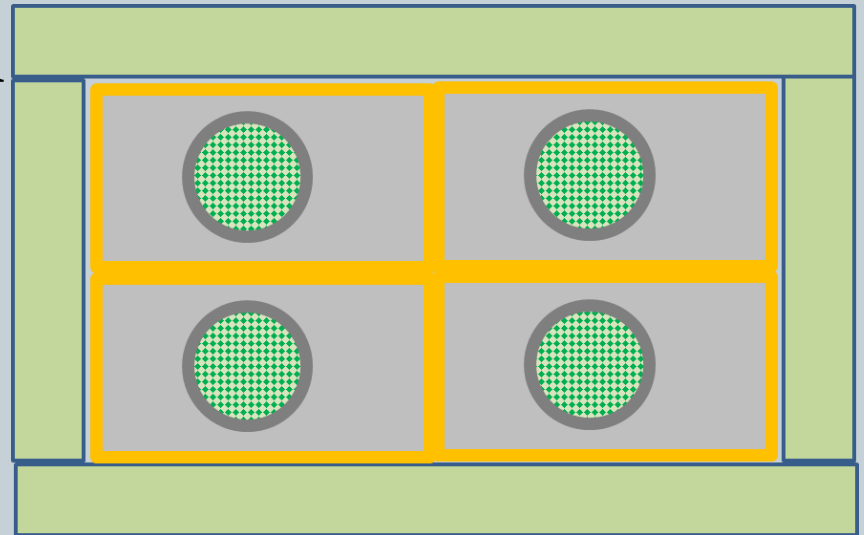
- SciBar@FNAL, hep-ex/0601022 of 2006.
 - SciNOvA P-1003, FNAL PAC 11/2010.
 - Leveraging existing tech.
 - ✦ Readout with Hamamatsu SiPMs.
 - ✦ Small DAQ from SciNOvA.
 - ✦ Slow controls as in MicroBooNE.
 - ✦ Analysis methodology from NOvA.



Dark Photon detector , Stage 2

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- Array of dipoles
 - Inspired by the IAXO exp.
- A 2x2 array + veto can fit on a movable platform.
- By the time of proposal the anticipated High Field technology may achieve the projected 15 T.

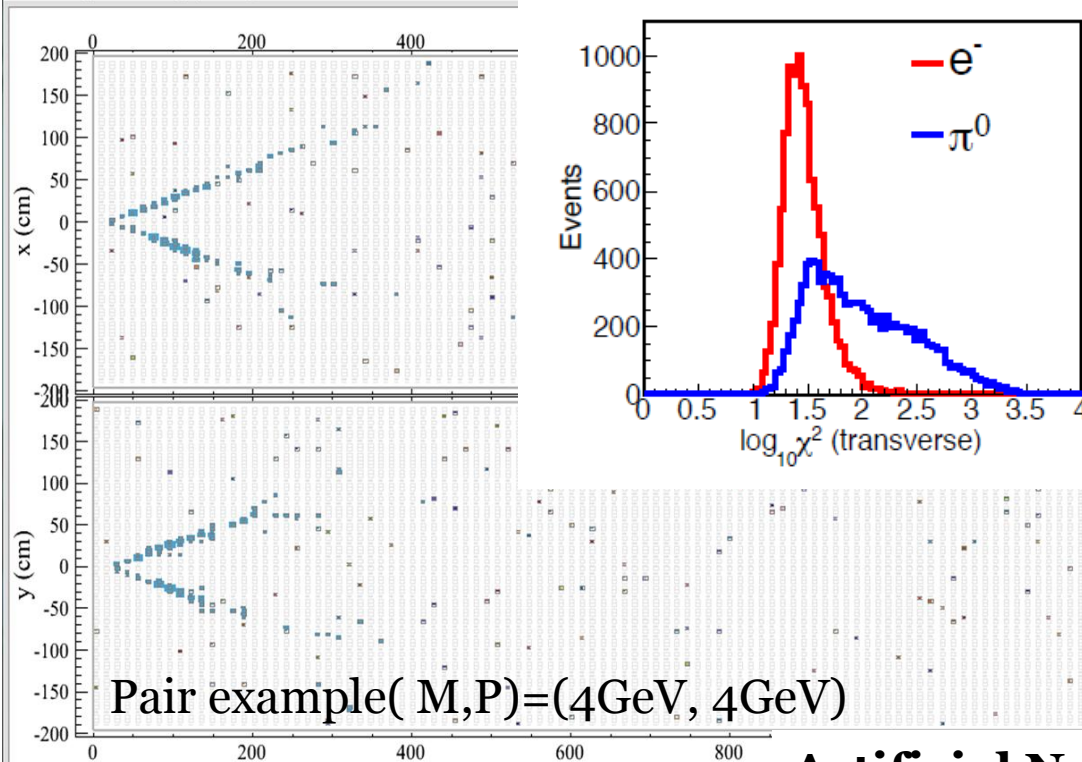


Analyzing the signal from NOvA ND

(21)

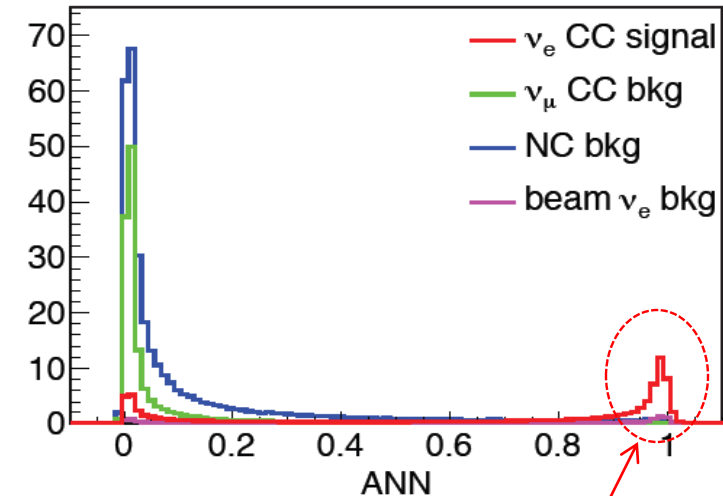
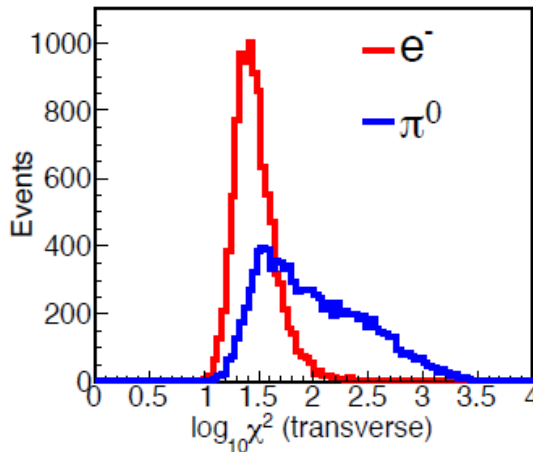
File Edit Window Job Help

<- Previous Next -----> Reload



Distinguishing electrons from pions

Events



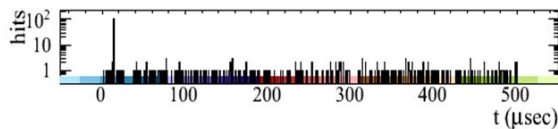
NOvA - FNAL E929

Run: 1 / 1

Event: 1 / NuMI

UTC Thu Jan 1, 1970

00:00:0.005000000

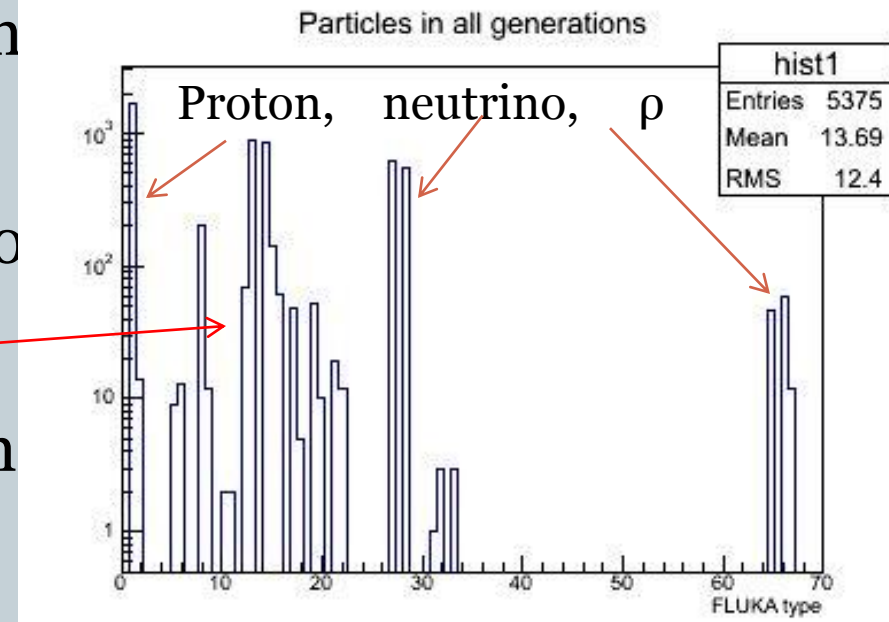


Artificial Neural Network (ANN). Electrons are identified using their shower energy profiles. Longitudinal and transverse log likelihoods for each particle hypothesis are calculated based on dE/dx information. Electron energy resolution nearly 10% at 2.0 GeV.

Flux predictions from the neutrino target

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- Models predict the mass of the particle and the branching ratio (BR) from the primary reaction in the target.
- Many types/masses/sizes of particles available for simulation without creating an unknown ALP in GEANT 4
- This basically the purpose of the search.



Workshop on Hidden Sectors from Physics generators.

1-5 Sept. 2013

**International Conference on Mathematical
Modeling in Physical Sciences, IC-MSQUARE**

